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A COST-BENEFIT ANALYSIS ON THE DELETION OF THE INERTIAL UPPER STAGE FACTORY ACCEPTANCE TESTING VERSUS A DECREASE IN MISSION RELIABILITY

THESIS

Michael H. Horn, Captain, USAF

AFIT/GSM/ENS/91S-13

DEPARTMENT OF THE AIR FORCE

AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Systems Management

Michael H. Horn, B.S.

Captain, USAF

September 1991

Approved for public release; distribution unlimited

Preface

The initial purpose of this analysis was to determine whether the Inertial Upper Stage factory acceptance test could be eliminated from future processing without decreasing the reliability of the vehicle. However, it soon became apparent that the deletion of any vehicle testing had to have some effect on reliability. Therefore, the study progressed from a simple anomaly analysis to a cost-benefit analysis; not an easy task for an electrical engineer by trade. Although this limited analysis makes the findings inconclusive, the methodology presented here seems to give some promising results and should be continued, as it could be of significant value in reducing total program costs.

The success of this research relied upon a team effort. I am deeply indebted to Major Dave Luther at Cape Canaveral AFS for providing the data used in this effort and to the Aerospace Corporation for validating the results of the anomaly analysis. I also wish to thank my faculty advisor, Major Thomas S. Kelso, for supporting this effort from the beginning and making me write a worthwhile paper. A word of thanks is also owed to my reader, Mr. Ralph Liebhaber who enlarged my ego by always complimenting my work no matter how bad it really was. Finally, I wish to thank my wife Mary Ellen for driving me home on those nights when I went out to release my frustrations and forget about this thesis.

Michael H. Horn

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Abstract

This study investigated the benefits attributable to deleting the factory acceptance testing for the Inertial Upper Stage (IUS) space booster and the possible impacts on mission reliability. A review of the literature revealed limited research on the advantages or disadvantages of performing acceptance testing on commercial programs. However, a review of DoD policy recognized the advantages of cost and time savings when developmental and operational tests are combined.

An analysis was performed on the anomalies that occurred during the acceptance testing for the seven vehicles involved in this study to determine whether all hardware defects would be detected by a later phase of testing. The research suggested that only two chance failures would be undetected by flight testing resulting in a decrease in reliability of .03%. The costs of the launch vehicle, the IUS, and a generic satellite were then used to calculate a cost of $103,500 for this decreased reliability. A cost-benefit analysis suggested that a savings of $646,500 per IUS vehicle could be achieved with minimal impact on reliability if acceptance testing was eliminated. The study concluded that current reliability could be maintained by additional flight testing but further research was necessary before a modification to the program could be implemented.

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I. Introduction

Overview

This chapter discusses the involvement of the United States Air Force and the Department of Defense in the acquisition and management of current space systems and introduces the philosophies and concepts of space systems testing. Next, the specific purpose and justification of the research is explained, the scope and limitations are addressed, and the chapter concludes with research objectives and questions.

Background

The Department of Defense (DoD) has become increasingly involved in developing, purchasing, and managing space systems with the United States Air Force (USAF) playing a major role in the acquisition process. This idea is illustrated by the fact that throughout the 1980s the DoD space budget has grown larger than the total National Aeronautic and Space Administration (NASA) budget (26:1). Not only is the Air Force increasing its space budget, but other government and military agencies are also increasing their space budgets. Currently, Space Station Freedom is

under development by NASA, while the Air Force is planning and developing several other space programs including the Strategic Defense Initiative (SDI) and the National Aerospace Plane (NASP) (2:12).

Space systems provide and encompass a broad range of capabilities and uses including exploration, scientific and technological development, communication, meteorology, and surveillance (25:3). NASA is responsible for the civilian applications and development of space systems while the DoD is responsible for all military aspects of space. As the primary developer of space systems for the DoD, the Air Force has many organizations involved in the development and management of space assets. Currently, space systems are developed within the USAF by Air Force Systems Command (AFSC) and operated by Air Force Space Command (AFSPACECOM). Many of the major commands in the USAF including the Strategic Air Command, Military Airlift Command, and Tactical Air Command rely on space systems for their daily operations (25:6). Because each of these organizations uses space systems differently, the development of the space systems must cover a broad range of requirements, objectives, and applications. Of extreme importance to operational availability is the extent and validity of testing prior to system issuance to the operational force.

However, with the increased emphasis on space systems comes the increased technology necessary for operating the systems, and therefore, higher costs. A major portion of

the total systems cost for space systems will come from the component and systems testing that maintains high reliability. This fact stems from the unique access limitations imposed on space systems. In most industries, one's capital assets are available for repair, improvement, or refurbishment. A space asset, once launched, is normally inaccessible. Therefore, sophisticated testing was developed to assure high mission reliability, but this results in high program and operating costs (27:298).

The acquisition process for space systems came under intense criticism in the late 1960s and the early 1970s because of costly development overruns, schedule slippages, and system performance shortcomings. The President's Blue Ribbon Defense Panel, the General Accounting Office, the Congress' Commission on Government Procurement, and the Armed Services Committees of the House of Representatives and Senate have consistently identified test and evaluation as a major problem area (8:13). The DoD responded to the criticism by issuing new guidelines for the acquisition process. These directives stated that testing will commence as early as possible and be conducted throughout the system acquisition process, and that program schedules and milestone decisions will be based upon accomplishment and assessment of the program's testing efforts. But testing is costly, difficult, and time consuming. There are many people involved and genuine competition exists between contractors for scarce defense dollars.

However, aerospace vehicle testing is a critical key to the overall vehicle processing flow since testing begins at the program's origin and does not end until the mission is complete. The initial attempt at detecting hardware failures after component production and assembly is the acceptance test. This testing process is the primary test screen for workmanship defects (24:71).

Regardless, acceptance testing is an area that many contractors believe has changed the most since the beginning of the space age. Research has been performed that studied the system effectiveness of development, qualification, acceptance, and flight-test phases for spacecraft launch vehicles; but no studies have exclusively investigated acceptance testing, although test program optimization must always consider the interrelationships among all four test phases. One company estimated that just twenty years ago, four out of every 100 engineers were involved in testing, but today testing includes almost 50 out of every 100 engineers working in space programs (10:11-83). In some cases, "the test equipment required on space projects is more sophisticated and of higher technology than the spacecraft the test equipment was designed to test" (10:11-84). Unfortunately, acceptance testing still tends to be more of an art than a science.

Problem Statement

Air Force Systems Command has requested that all operational space launch programs evaluate their current assembly, test, and launch operations for possible cost reductions. This request is part of the Air Force's attempt at Total Quality Management (TQM) to eliminate unnecessary operations and repetitive processing. Therefore, the Chief of the Inertial Upper Stage Engineering Division at Cape Canaveral Air Force Station (CCAFS), Florida has requested a study to evaluate the current processing of the Inertial Upper Stage (IUS).

The IUS, flown aboard the space shuttle or atop a Titan expendable launch vehicle, is designed to transport a variety of Department of Defense and National Aeronautics and Space Administration spacecraft from low-earth orbit to geosynchronous or planetary-exploration orbits. The IUS currently undergoes two phases of testing to detect design faults and workmanship defects. Acceptance testing is performed at the factory after assembly of the IUS is complete. After successful completion of the first test phase, the IUS is disassembled and shipped to CCAFS for reassembly. Flight testing is then performed to detect possible shipping damage and to verify electrical connections. The tests performed during both test phases are almost identical except for the location site.

Research Objectives

The research objective of this paper is to complete an analysis of the existing Inertial Upper Stage processing to determine if any of the repetitive testing could be eliminated from the processing flow. The research will also address the cost savings associated with the possible deletion of testing and the effect on overall system reliability. Finally, conclusions and recommendations will be made based upon this research.

Research Questions

This study will ask the following questions in support of the research objectives:

1. How many vehicles should be analyzed for anomalies?
2. Which test phase is the better candidate for elimination?
3. What design faults or workmanship defects will go undetected?
4. How much money can be saved?
5. What is the effe[illegible] vehicle reliability?
6. What is the relationship between cost savings and the possible change in reliability?
7. What conclusions and recommendations can be drawn from this research?

Scope and Limitations

The scope of this project is aimed at providing general background information on the IUS program, the current factory acceptance testing performed on the IUS, and the purpose for performing this particular testing. Because of the technical complexity involved in these issues, this project provides only enough technical information to understand the current program and testing process.

Summary

This introductory chapter discussed the development and management of USAF space systems, the reason for the current test directives of the Department of Defense, and the importance of the testing procedure in the space systems processing flow. The problem statement, research objectives, and research questions were discussed as well as the scope and limitations of this project.

Chapter II, Literature Review, describes the current IUS development, project management, processing and testing methodologies, and summarizes several of the prevalent DoD publications on test and evaluation, as well as other professional publications on reliability and testing.

II. Literature Review

During the 1980s there has been a large amount of activity and change in the use and development of space systems. The dependence on space systems by the nation and the military has increased tremendously. To understand the impacts of space systems testing and the acquisition process associated with space systems, several aspects of the space policy should be studied. This chapter will first present a current view of the IUS development, project management, and testing methodology. The remainder of the chapter will be devoted to a review of the prevalent publications on test and evaluation, as well as other professional publications on reliability and testing.

Overview of the Inertial Upper Stage

The Inertial Upper Stage (IUS) is a flexible two-stage space vehicle capable of transporting a variety of critical Department of Defense (DOD) and National Aeronautics and Space Administration (NASA) spacecraft to geostationary orbits. The IUS can be flown aboard the space shuttle or atop a Titan expendable launch vehicle to meet the operational space needs of the DOD and NASA (9:3). Air Force Systems Command's Space Systems Division, headquartered at Los Angeles AFB, manages acquisition and operation of the program. Launch operations are performed at Cape Canaveral Air Force Station (CCAFS) for Titan

missions and at the Kennedy Space Center (KSC) for shuttle missions.

The IUS vehicle measures approximately 17 feet in length and 9.5 feet in diameter. At launch, the IUS weighs approximately 33,000 pounds and is capable of delivering a satellite of roughly 5000 pounds or less to geostationary orbit. Each stage of the IUS contains a solid-propellant rocket motor to provide the thrust needed to perform the transfer of the payload to the required orbit. Onboard computers and an inertial measurement unit guide the vehicle during flight to the final orbit. The system's software monitors and controls the vehicle subsystems to ensure a high degree of accuracy and reliability. (5)

Both the Titan expendable launch vehicle and the space shuttle are limited to low altitudes between 80 and 500 nautical miles. Since many military and scientific satellites require altitudes of more than 19,000 nautical miles above the earth, the Air Force and NASA requested the development of an upper stage capable of transporting a 5000-pound satellite to these high-energy orbits (9:6). Therefore, in 1975 the IUS program was initiated to provide a capability of transporting satellites to high-earth orbit and to planetary trajectories with great accuracy and reliability (5).

For a typical shuttle mission, the IUS rides in the orbiter's cargo bay during the ascent phase until the orbiter reaches a low-earth orbit between 100 and 500

nautical miles. After the cargo bay doors are opened on orbit, the IUS and its payload perform a final system checkout and then are deployed from the cargo bay. The IUS then boosts the spacecraft to its geosynchronous orbit of approximately 22,300 nautical miles above the earth.

A similar sequence occurs when the IUS is launched on a Titan expendable launch vehicle. Once the Titan reaches a low-earth orbit between 80 and 120 nautical miles, the IUS and spacecraft separate from the launch vehicle. The IUS then continues the mission of transferring the spacecraft to the desired geosynchronous orbit.

Since its second launch on April 4, 1983, the Inertial Upper Stage has proven to be an effective and reliable space booster with twelve successful missions (4). Additionally, the IUS was used on each of the first three shuttle missions following the Challenger accident. Its proven safety and reliability have made it the upper stage "work-horse" through the early 1990s (9:3).

Currently, the IUS begins the testing process at the Boeing Aerospace Company's factory in Kent, WA approximately two years before launch. This factory acceptance testing is the initial attempt at detecting hardware failures after component production and assembly and is the primary test screen for workmanship defects (24:71). Upon successful completion of acceptance testing, the IUS is disassembled and shipped to Cape Canaveral for reassembly and further testing. This in-service or flight testing repeats the

factory acceptance testing and ensures the proper reassembly of the IUS before launch operations.

Overview of Test and Evaluation

The fundamental purpose of test and evaluation (T&E) in a defense system's development and acquisition program is to identify the areas of risk to be reduced or eliminated. During the early phases of development, T&E is conducted to demonstrate the feasibility of conceptual approaches, to minimize design risk, to identify design alternatives, to compare and analyze tradeoffs, and to estimate operational effectiveness and suitability (6:516). As a system undergoes design and development, the emphasis in testing moves gradually from development test and evaluation (DT&E), which is concerned chiefly with the attainment of engineering design goals, to operational test and evaluation (OT&E), which focuses on questions of operational effectiveness, suitability, and supportability. Although there are usually clearly separate development and operational test events, DT&E and OT&E are not necessarily serial phases in the evolution of a weapon system.

The terms "test" and "evaluation" are an integral part of the entire vehicle processing. Test denotes the actual testing of hardware to obtain data valuable in developing new capabilities, managing the developing activities, or making decisions at program milestones or on the allocation of resources. Evaluation denotes the process whereby the

information content in the data is logically assembled and analyzed to aid in making systematic decisions. Overall, T&E may be defined as:

> the physical testing, experimentation, and analyses performed during the course of research, development, introduction, and employment of a weapon system or sub-system, and the analytical or evaluative studies performed using the data generated. (8:18)

T&E is an integral part of all phases of the development of systems and provides information for different purposes and for different users. First, testing of systems under development is an inherent part of the research and development process through which hardware deficiencies and operational problems are identified and resolved. This testing provides design data feedback to the developing agency and development contractors. Second, T&E provides the basis for the decision of continuing the acquisition process at major program milestones. To initiate advanced deployment, to conduct full-scale development, and to produce a system are major processing milestones that require the best information possible to aid the decision process. Third, information obtained through development and operational testing provides a valuable data base that the operational command can use in establishing system doctrines. Finally, T&E provides the decision maker with a means to make judgements and to assess the technical, managerial, schedule, and cost risks of the project under study (8:19-20).

DOD Policy on Testing

In the early 1970s, DoD test policy became more formalized and placed greater emphasis on test and evaluation as a continuing function throughout the acquisition cycle (6:521). These policies stressed the use of T&E to reduce acquisition risk and provide early and continuing estimates of the system's operational effectiveness and operational suitability. To meet these objectives, appropriate test activities had to be fully integrated into the overall development process. From a systems engineering perspective, test planning, testing, and analysis of test results are integral parts of the basic product definition process (6:521).

Department of Defense Instruction (DODI) 5000.2, Part 8 provides the guidelines for test and evaluation for the DoD and replaces DoD Directive 5000.3. Specifically, DODI 5000.2 regulates that all DoD test and evaluation programs be structured to:

1. Provide information for assessment of acquisition risk;
2. Verify attainment of technical performance specifications and objectives;
3. Verify that systems are operationally effective and suitable for intended use; and
4. Provide essential information in support of decision making. (7)

Additionally, general policy dictates that any production decision be supported by a formal phase of operational test and evaluation or an operational assessment which addresses measures of performance with appropriate

quantitative criteria and test limitations. However, these policies do not require the IUS to implement both acceptance testing and flight testing, but allow for the use of existing test facilities and resources wherever practical. The instruction states, "A combined developmental test and evaluation and operational test and evaluation approach should be considered when there are time and cost savings" (7).

Developmental test and evaluation programs are intended to identify potential operational and technological limitations of the concepts and design and to support the identification and description of design risks. Essentially, this test phase substantiates that contract technical performance and manufacturing process requirements have been achieved and certifies that the system is ready for operational test and evaluation. Qualification testing is a form of development testing that verifies the design and manufacturing process. Preproduction qualification tests are formal contractual tests which confirm the integrity of the system design over the specified operational and environmental range. Production qualification tests are conducted on production items to ensure the effectiveness of the manufacturing process, equipment, and procedures. These tests are conducted on each item or a sample lot taken at random from the first production lot, and the production qualification tests are repeated if the process or design is changed significantly,

or if a second or alternate source is brought on line. (6:531)

Operational test and evaluation programs are intended to determine the operational effectiveness and suitability of a system under realistic conditions and to determine if the minimum acceptable performance requirements have been satisfied. DODI 5000.2 defines operational effectiveness and operational suitability as:

> Operational Effectiveness - The overall degree of mission accomplishment of a system when used by representative personnel in the environment planned or expected for operational employment of the system considering organization, doctrine, tactics, survivability, vulnerability, and threat. (7)
>
> Operational Suitability - The degree to which a system can be placed satisfactorily in field use with consideration given to availability, compatibility, transportability, interoperability, reliability, wartime usage rates, maintainability, safety, human factors, manpower supportability, logistics supportability, documentation, and training requirements (7).

OT&E performed after the start of Full Rate Production may be known as Follow-on Operational Test and Evaluation (FOT&E) and is conducted during production and deployment. Preliminary FOT&E is conducted in order to assess the full system capability, to verify the correction of deficiencies, and to assess system training and logistics status. Subsequent FOT&E is conducted on production items throughout the life of a system. The results are used to refine estimates of operational effectiveness and suitability and to identify the need for modifications. (6:535)

Acceptance Testing

Acceptance testing is an integral part of the T&E process. Yet, acceptance testing still tends to be more art than science, and a survey by the American Institute of Astronautics and Aeronautics (AIAA) Technical Committee on Systems Effectiveness and Safety supports this impression. Anthony Smith and Thomas Matteson, operations analysts for General Electric, reported the results of this survey in the *Astronautics and Aeronautics Journal*. The survey asked test engineers to rate the effectiveness of acceptance testing in comparison with development, qualification, and flight testing. Respondents to the study questionnaire ranked acceptance testing no better than third for assuring reliability, maintainability, and safety (24:69). Additionally, the AIAA survey asked, "How important are development, qualification, acceptance, and flight tests in eliminating design problems in the product?" (24:70). The respondents lowered acceptance testing to a rather insignificant position showing that development and qualification tests are the more important tests for detecting design problems.

Overall, the survey results show that workmanship defects and design faults are the major contributors to space vehicle processing delays. More specifically, workmanship is the number one cause of failures in both ground and flight tests, and design faults are the number two cause of flight test failures (24:71). Yet, acceptance

testing, which is the primary screen for workmanship defects and is the only test run on every article prior to flight, was not considered a prime contributor to reliability or for detecting design problems. Smith and Matteson conclude,

> The survey clearly points to a need for a more scientific approach to the specification, planning, and conduct of test programs. It also indicates a need for rigorous industry-wide attack on the broader analysis and interpretation of test results -- with the aim of defining test methods, techniques, and practices that will yield more return per test dollar. (24:72)

Additionally, the general lack of standardized test criteria is also a concern. Edward Houston and Mark Phillips, space sector program managers at Los Angeles AFB, in a report for the 24th Space Congress, write that certain testing required to be performed in accordance with government specifications is excessive, redundant, and actually non-productive. Houston and Phillips suggest that the government participate in a program that encourages the industry to re-evaluate the testing process. More focus should be given toward lower-level testing that uses less costly and less dedicated equipment (10:11-84).

<u>Overview of Reliability and Reliability Testing</u>

The reliability of a device is a quality of that device, but it is not a quality which can be measured directly. Normally, except in a few rare instances, reliability cannot be measured at all but only estimated. Therefore, reliability can be defined as "the probability of

a successful operation of the device in the manner and under the conditions of intended customer use" (21:20). Stated simply, "reliability is the capability of an equipment not to break down in operation" (1:3).

David Lloyd and Myron Lipow in their book, *Reliability: Management, Methods, and Mathematics*, state that reliability is one of the primary concerns in the development of most military weapon systems, and that this emphasis can be seen in the changes that have occurred in the civilian industry. For example, reliability conferences have been organized, reliability departments have been formed, reliability programs have been written, and reliability requirements now appear in specifications and contracts. On the other hand, unreliability has consequences in cost, time wasted, the psychological effect of inconvenience, and in certain instances personal and national security (21:1).

Generally, the cost of unreliability is not only the cost of the failing item but of the associated equipment which is damaged or destroyed as a result of the failure. The reason is the interdependency between components in complex systems. For example, the failure of a transistor in a home radio would generally cost the amount needed to replace it. Conversely, the failure of a similar transistor in a space vehicle might prevent a motor staging from occurring, leading to the subsequent loss of the satellite at a tremendous cost.

The budget is generally the limiting consideration in

the development of any item or system. Reliability's share in the budget has become somewhat controversial. In the early stages of a program, reliability is costly since it requires certain expense activities such as organized and efficient planning, testing, and reporting without being immediately able to demonstrate its worth compared with the initial outlay (21:3). However, as soon as this initial period is passed, the higher reliability obtained will begin to save money because of fewer failures and decreased maintenance. "Since we cannot hypothesize about what did not happen, it is difficult therefore to demonstrate the net savings due to reliability" (21:3).

Well-designed, well-engineered, thoroughly tested, and properly maintained equipment should never fail in operation. However, experience shows that even the best design, manufacturing, and maintenance efforts do not completely eliminate the occurrence of failures (1:3). In the book *Reliability Theory and Practice*, Igor Bazovsky discusses the three characteristic types of failures which may be inherent in any equipment and which may occur without any fault on the part of the operator.

First, there are the failures which occur early in the life of a component. They are called "early" failures and in most cases result from poor manufacturing and quality-control techniques during the production process. Early failures can be eliminated by the "debugging" or the "burn-in" process. The debugging process consists of operating

the equipment for a number of hours under conditions simulating actual use. When substandard components fail in these early hours of operation, they are replaced by good components. The burn-in process consists of operating a lot of components under simulated conditions for a number of hours, and then using the components which survive for the assembly of the equipment. (1:3)

Secondly, there are failures which are caused by "wearout" of parts. These occur in equipment only if it is not properly maintained or not maintained at all. The age at which wearout occurs differs widely with components. In most cases wearout failures can be prevented by replacing at regular intervals the accessible parts which are known to be subject to wearout, and to make the replacement intervals shorter than the mean wearout life of the parts. However, when the parts are inaccessible, they are designed for a longer life than the intended life of the equipment. This second method is also applied to "one-shot" equipment such as space vehicles which are used only once during their lifetime. (1:4)

Thirdly, there are "chance" failures which neither good debugging techniques nor the best maintenance practices can eliminate. These failures are caused by sudden stress accumulations beyond the design strength of the component. Chance failures occur at random intervals which makes their prediction difficult. However, chance failures obey certain rules of collective behavior so that the frequency of their

occurrence during sufficiently long periods is approximately constant. (1:4)

Reliability theory and practice differentiate between early, wearout, and chance failures for two main reasons. First, each of these types of failures follows a specific statistical distribution and therefore requires a different mathematical treatment (1:5). Secondly, different methods must be used for their estimation (1:5). Because the failure-free operation of space system equipment is vital to the preservation of human lives, to defense, and to industry, it must be highly reliable. In such equipment, early failures should be eliminated by thoroughly prolonged testing and check-out before it is put into service. Wearout failures should be excluded by correctly scheduled, good preventative practices. Then, if failures still occur during the operational life of the equipment, they will almost certainly be chance failures. Therefore, when such equipment is in operational use, its performance reliability is determined by the frequency of the chance failure occurrence.

In the development of contemporary defense systems, attention must be given to the planning and evaluation of environmental tests which yield a maximum amount of reliability at a minimum cost. In the article, "Reliability Test Optimization," the authors discuss the desirable and undesirable features of various test philosophies which are associated with the reliability testing of missile and space

vehicle components. First the authors state,

> Unless the test program is carefully planned as to the environmental level and test time for each component, the resulting reliability information may be misleading. Without careful planning, equipment which operates on a short duty cycle will be tested to an inordinately larger number of equivalent mission life times and more importantly, continuously operating equipment may be tested to an insufficient equivalent mission life. (22:87)

Secondly, major test plans must consider the equipment level at which the testing in accomplished. There are advantages and disadvantages to testing at the component level and at the system level. It would be advantageous from a financial viewpoint if all environmental testing would be postponed until the entire space vehicle could be completely assembled. However, experience has shown that this is not practical since feedback information would be available too late in the program for necessary corrective action (22:88). Another important consideration is the simulation of the true environment in the test laboratory. The authors state,

> It would be interesting to reproduce the total combined actual mission environment when testing for reliability. However, this is prohibitively expensive in most cases, and based on analytical assumptions, it is usually not necessary in order to measure reliability with confidence. (22:88)

S. H. Chasen in his article, "Optimum Developmental Launch Programs," agrees with this idea. He believes that it is not considered satisfactory to base launch programs on vehicle reliability estimates alone but that demonstrated vehicle reliability is mandatory. Yet, Chasen states, "to

demonstrate a required level of vehicle reliability with high confidence by statistical test programs would be too costly both in money and in elapsed time" (3:99). Adequate reliability testing is demanded in modern space system development. Therefore, system reliability can be provided through equipment design and by requiring a test program to measure and assure actual reliability attainment by continually assessing the test results.

Systems reliability can be measured in percentages, such as 99.99%, with the principle that in aerospace hardware each '9' in reliability raises the cost by a factor of ten (11:311). Therefore, a re-evaluation of the acceptance testing process that only slightly decreases the reliability will lower the overall program costs.

Summary

Test and evaluation serves a number of useful functions and provides information for a variety of customers. T&E provides information to developers to assist in the identification and resolution of technical difficulties. T&E provides information to decision makers responsible for making the investment decisions to procure a new system and for deciding on the most effective use of limited resources. Moreover, T&E provides information to operational users to support the development of effective tactics, doctrine, and procedures. DoD Instruction 5000.2 outlines the policies regarding T&E, including both DT&E and OT&E. Although they

are usually clearly separate test events, they are not necessarily serial phases in the evolution of a major defense system. In fact, combined and concurrent development and operational testing is encouraged when appropriate.

The history of the Inertial Upper Stage program has demonstrated the proven reliability and effectiveness of this space booster. Therefore, the program's current testing philosophy, which includes acceptance testing, has been shown to produce a reliable vehicle. Yet in the discussion of acceptance testing, both good and bad points of maintaining this testing were expressed.

Houston and Phillips conclude that today's contractors are placing more emphasis on testing by employing more engineers in the acceptance testing phase of program development, but this is increasing the overall program's costs by orders of magnitude non-proportional with increases in reliability. Houston and Phillips argue that more focus should be given toward lower level testing, using less costly, less dedicated equipment (10:11-84).

Additionally, Smith and Matteson argued that acceptance testing as the primary test screen for workmanship defects and design faults was not considered to be a prime contributor to program reliability. Could it be that acceptance tests, as they are conducted today, are, in truth, not all that good? Are acceptance tests really as poorly thought of as the survey indicated? The research

methodology employed here will evaluate the current testing practices as they relate to the IUS program and attempt to answer these questions, as well as the research questions.

As a result of this review of the IUS program, DoD policy of test and evaluation, and acceptance testing, a cost-benefit study is in order to determine whether the current testing practices are worth the money that is being invested. By analyzing each anomaly that arises during factory testing, one can determine whether the flight testing would identify these same problems and still maintain the overall mission reliability.

III. Methodology

Introduction

The research objective of this paper is to complete an analysis of the existing Inertial Upper Stage processing to determine if any of the repetitive testing could be eliminated from the processing flow. The research will also address the cost savings associated with the possible deletion of testing and the effect on overall system reliability. This chapter presents the approach used in answering the following research questions which were initially posed in Chapter I.

1. How many vehicles should be analyzed for anomalies?
2. Which test phase is the better candidate for elimination?
3. What design faults or workmanship defects will go undetected?
4. How much money can be saved?
5. What is the effect on vehicle reliability?
6. What is the relationship between cost savings and the possible change in reliability?

Additionally, this chapter will discuss the type of data being researched, the location of data sources, and the methodology used to answer these research questions.

Population of Concern

Since the program's initial conception in 1978, thirteen IUS vehicles have successfully completed factory

acceptance testing and launch operations. From 1978 until January of 1986, there were minimal changes in the testing process and test operators. However, after the explosion of the space shuttle Challenger in January 1986, IUS vehicle processing was delayed until the shuttle was cleared for flight. This forced Boeing Aerospace into a substantial layoff of test personnel and, subsequently, a large number of new personnel were brought into the program when the testing was resumed. Additionally, minor changes in the testing process were implemented because of recommendations of the accident investigation team. As a result, the number of vehicles that will be analyzed for the effect on reliability will be fewer than the thirteen vehicles that have completed factory testing and launch operations. (4)

This idea is supported by H. R. Lawrence and J. M. Vogel in their article "Some Thoughts on Reliability Estimation" which describes the complications involved in predicting reliability based on other vehicles. This approach ignores the fact that the design parameters of any two vehicles may be substantially different even though many of the materials and fabrication techniques may be the same (20:61). Lawrence and Vogel further state,

> Another serious objection to this approach is that individuals performing the design, program management, processing, and quality control functions in one program may be totally different from those associated with the other (20:61).

They conclude that under these conditions, it is safe to presume that "the reliability inherent in a new rocket

design will be degraded as the design is translated from a drawing to hardware more than was the case in earlier programs" (20:61).

Therefore, this research will analyze only those vehicles that have completed factory acceptance testing and have successfully finished their mission since 1986. A census of these seven IUS vehicles will provide approximately 400 anomalies for analysis.

Research Data

The research begins with obtaining anomaly listings from the factory acceptance testing of these seven IUS vehicles. These acceptance test logs are prepared by Boeing Aerospace and presented to a review team consisting of personnel from the IUS program office, from Cape Canaveral AFS, and from the Aerospace Corporation for government acceptance of the hardware. The review team determines whether all testing requirements have been met and whether all test anomalies have been successfully resolved before they sign the DoD Form 250, "Material Inspection and Receiving Report." Copies of these logs have been provided to support this research effort.

The anomalies will be analyzed and compared to the flight test procedures to determine whether the flight testing would detect all of the defects that occurred during the factory acceptance testing. If this "evaluation" research suggests that the flight test will detect many of

the factory anomalies, then the acceptance test could be eliminated from the IUS processing flow, which would reduce the total program costs. Unfortunately, the deletion of acceptance testing will eliminate one of the steps that detects design faults and workmanship defects which, in turn, might cause a decrease in vehicle reliability. If the research suggests that the flight test will detect the majority of the factory anomalies, then deleting acceptance testing may result in cost savings that are more substantial than the slight decrease in mission reliability.

Data Analysis

The next step of the research will be to determine which test phase, if any, is the better candidate for elimination. In order to answer this question, it is necessary to review the current IUS processing operations.

The IUS normally undergoes acceptance testing approximately three to four years before its scheduled launch. During this delay, the vehicle is put into storage at the factory until it is prepared for shipment to CCAFS. Because of the prolonged time in storage, some of the critical flight components are not used during the acceptance testing because they will surpass their storage limitations. For example, inert motors are used for factory testing until live motors are installed at CCAFS for the flight testing. Additionally, some of the electrical components will invalidate their calibrations during the

time in storage. For example, non-flight computers and guidance system components are used for factory testing before "pedigreed" components are installed for flight testing.

After completion of acceptance testing and storage, the IUS must be partially disassembled to remove the inert motors and because of the limitations imposed on transporting the vehicle from the factory to CCAFS. The IUS is then reassembled at CCAFS to perform flight testing and launch operations. The current program requirements dictate that any electrical connections that are broken must be totally retested after reassembly to ensure continuity and functionality (12:19). Therefore, the research should suggest that the acceptance test is the only logical test that may be eliminated.

The next step of the research process will involve the data analysis. The IUS acceptance test logs list every anomaly that occurred during the factory acceptance testing and summarize the details of the anomaly. Each anomaly will be analyzed and categorized into one of four types of failures. These four classes will be labeled as:

1. Paper
2. Operator
3. Test Equipment
4. Hardware

Paper anomalies will include all problems that were the result of an error in the test procedure or in the test requirements. Operator anomalies are the result of the test conductor performing the test steps incorrectly or out of

sequence when the test procedure is actually correct. This class of anomaly is different from the paper classification in which the test procedure is incorrect. Operator anomalies will also include all instances in which test personnel inadvertently affected the IUS vehicle. Test equipment anomalies are caused by an error or a failure in the ground support equipment (GSE) that is used in the testing process. This classification will also include failures in the test facility power or environment. Hardware anomalies are a result of an actual defect in the flight hardware and may be caused by design flaws or workmanship defects. This classification will include both mechanical and electrical anomalies. However, only the electrical anomalies are significant since the acceptance testing being studied is exclusively related to electrical problem detection. Acceptance testing is designed to detect these electrical hardware defects because they adversely affect vehicle reliability.

This information will then be compared to the current flight testing at CCAFS to determine whether this phase of testing would detect the same electrical hardware anomalies that occurred during the acceptance test phase. The operator and test equipment anomalies are not a concern to this study because they are unique to the test location and should not affect the vehicle reliability. The paper anomalies also will not affect reliability, but they may cause delays in the flight testing. Some of the same

procedures and requirements are used at both test locations, therefore, any paper problems that are discovered at the factory will increase the effectiveness of the test operations at CCAFS. However, it is desired that all electrical hardware defects will be detected by the flight testing.

The anomaly classification and analysis will be submitted to a group of systems engineers as listed in Appendix B from The Aerospace Corporation (ASC) at CCAFS. ASC serves as a technical advisor to the Air Force on test and launch operations and has agreed to review the categorized data for validity. The approval of the data by this group of experts will validate this phase of the research and will allow further analysis on the data.

The next phase of the research will involve determining the possible affect on reliability. System reliabilities are calculated by means of the calculus of probability. To apply this calculus to systems, one must determine the probabilities of its parts, since they affect the reliability of the system. Therefore, "to calculate system reliability one must have a knowledge about the reliabilities of those components which can cause the system to fail" (1:85). Under the current testing scenario, the IUS operates to a theoretical reliability of 99.73% (23). This probability is obtained from the combination of the fifteen serial and parallel components listed in Table 1. For those systems with two components, the reliability is

based on a "standby" parallel redundancy. The reliabilities of these components are derived from individual tests which yield information about their respective failure rates.

TABLE 1

COMPONENTS USED TO DERIVE SYSTEM RELIABILITY

COMPONENT	NUMBER
Computers	2
Motors	2
Power Distribution Unit (PDU)	2
Power Transfer Unit (PTU)	1
Pyro Switching Unit (PSU)	1
Redundant Inertial Measurement Unit (RIMU)	1
Signal Conditioning Unit (SCU)	2
Signal Interface Unit (SIU)	1
Thrust Vector Controller (TVC)	2
Transponder	1

As discussed in Chapter 2, reliability theory has determined that, for all practical purposes, system reliability measurements are limited to the exponential case. "This is the period when the system is new, possibly debugged, and before the components get a chance to fail of wearout" (1:247). In this case, the system is subject to failures that occur at a constant rate, and the reliability can be defined by the exponential formula

$$R(t) = e^{-\frac{t}{m}} \tag{1}$$

where

$R(t)$ = reliability
t = operating time for system
m = mean time between failures (1:19)

System reliability measurements consist of an estimation of the systems's mean time between failures from a number of times between two successive system failures as obtained during testing. As the system is tested, the total accumulated operating time is measured, and the number of chance failures which occur during the test are counted. The best estimate of the system's mean time between failures is then obtained as

$$m = \frac{T}{r} \quad (2)$$

where

m = mean time between failures
T = total accumulated operating time
r = number of failures (1:248)

When more than one system is operated simultaneously, as in the case of IUS acceptance testing, the total operating time becomes

$$T = \sum_{i=1}^{n} t_i \quad (3)$$

where

T = total accumulated operating time
n = number of components in system
t_i = operating test time of each system (1:248)

The IUS contract calls for acceptance testing to be completed over 55 days with an 8-hour-per-day cycle. However, for the vehicles in this study, the average total test time has actually been 66 days per vehicle. Of this time, approximately 1/2 or 33 days have been devoted to the electrical portion of the acceptance testing. Therefore, the operating test time (t_i) for each of the fifteen critical components listed in Table 1 is calculated to be 264 hours. Then, using Equation (3), the total accumulated operating time (T) is 3960 hours. (23)

An estimate of the decrease in vehicle reliability must be made if all of the hardware anomalies from acceptance testing would not be detected during flight testing. This estimate of the new vehicle reliability will be calculated by first determining the mean time between failures (m) using Equations (2) and (3) and then by calculating reliability using Equation (1). In these calculations, *r* will equal the number of anomalies encountered during acceptance testing that would not be detected by the current flight testing, and *t* will equal the mission life of a typical IUS vehicle. The estimated new reliability can then be summarized as

$$R_{New} = e^{\frac{t \cdot r}{n \cdot t_i}} \qquad (4)$$

If the new vehicle reliability is substantially smaller than the theoretical reliability of 99.73%, then additional test procedures to be implemented into the flight tests to detect all the hardware anomalies will be suggested.

Cost-Benefit Analysis

After completion of all anomaly analysis, the cost of performing each IUS acceptance test will be obtained. With this data, the average cost per anomaly can be determined, as well as the average cost of each type of anomaly per vehicle. This information can then be used to infer the average cost of performing factory acceptance testing and, therefore, the average vehicle cost savings if acceptance testing is eliminated. However, the research must also quantify in terms of cost the estimated decrease in reliability that was discussed earlier in this chapter and calculated using Equation (4).

The expected cost of a decrease in reliability is a function of the cost of the launch vehicle processing, the upper stage, and the satellite. This cost-benefit analysis will assume the use of the Space Transportation System (STS) with an average cost of $200 million per launch, the IUS with an average cost of $60 million and a theoretical reliability of 99.73%, and a non-specific satellite with an average cost of $85 million. The expected cost of decreased reliability can be calculated as

$$Cost = (R_{Current} - R_{New}) * (C_{LV} + C_{US} + C_{SC}) \tag{5}$$

where

$Cost$ = Expected cost of reliability decrease

$R_{Current}$ = Current theoretical reliability of IUS

R_{New} = Estimated new reliability of the IUS

C_{LV} = Cost of launch vehicle processing

C_{US} = Cost of the IUS vehicle

C_{SC} = Cost of spacecraft (23)

Once this cost determination is made, it can be compared to the average cost of performing the electrical portion of the acceptance test. A cost of decreased reliability lower than the electrical test costs would indicate the possibility of achieving cost savings by deleting the electrical portion of the IUS acceptance testing. Conversely, a higher reliability cost would indicate that the costs saved by deleting acceptance testing would not be worth the decrease in mission reliability.

Summary

This chapter presented the methodology that will be used in classifying the IUS acceptance test data, analyzing the data, estimating the decrease in reliability, and estimating the average costs of acceptance tests and test anomalies. The results of the data analysis as performed by this researcher are not, by themselves, adequate to be considered valid; therefore, the results will be submitted

to a panel of experts from the Aerospace Corporation for approval and validation.

The next chapter, Findings and Analysis, presents the results of the data analysis and the cost-benefit analysis with summaries of the data collected.

IV. Findings and Analysis

Overview

This chapter presents the results of the data analysis performed on the seven IUS acceptance test logs and discusses those anomalies that might impact the reliability of the IUS vehicle. The anomalies discovered during acceptance testing that would not be detected by flight testing are used as the basis for estimating the decrease in reliability. This estimate is then used to calculate the cost of decreased reliability. Finally, the results of the reliability estimation and the cost-benefit analysis are presented.

Findings of Data Analysis

Each anomaly in the IUS acceptance test logs was analyzed and categorized into one of four types of failures. These four classes of failures were labeled as:

1. Paper
2. Operator
3. Test Equipment
4. Hardware

Paper anomalies included all problems that were the result of an error in the test procedure or in the test requirements. Operator anomalies were the result of the test conductor performing the test steps incorrectly or from inadvertently affecting the vehicle. Test equipment anomalies were caused by failures in the ground support equipment (GSE) or the test facility. Hardware anomalies

were caused by design failures or workmanship defects and included both mechanical and electrical anomalies. However, only the electrical anomalies were significant to this study since the acceptance test is exclusively related to electrical problem detection. The hardware problems and resolutions of the factory acceptance testing as presented to the USAF for acceptance of the seven IUS vehicles involved in this study are summarized in Appendix C.

The hardware problems that were listed in the test logs were compared to the flight testing that is currently being performed at CCAFS to determine whether this phase of testing would detect the same electrical hardware anomalies that occurred during the acceptance test phase. The results of this analysis for each IUS vehicle under study are presented in the following sections.

IUS-5. There were five hardware anomalies associated with factory testing of the IUS-5 vehicle. Anomaly #2 and Anomaly #4 were mechanical problems that were discovered in the vehicle assembly and de-stack operations. Both of these mechanical problems would have been detected during the assembly of the IUS at CCAFS.

Anomaly #3 concerned a faulty accelerometer and was discovered after performing acoustic testing. However, this paper only suggests deleting the electrical portion of the acceptance testing and is not recommending the deletion of acoustic testing. Therefore, this anomaly would not affect the mission reliability.

Anomaly #1 and Anomaly #5 were electrical problems associated with the Thrust Vector Controller (TVC) and the Redundant Inertial Measurement Unit (RIMU) which are two of the critical components that affect reliability. However, both of these anomalies would have been detected by the electrical flight testing, and therefore, would not have decreased reliability.

IUS-6. There were 41 hardware anomalies associated with factory testing of the IUS-6 vehicle. Seven of these anomalies concerned problems detected during the electrical testing while 34 problems were encountered in the vehicle assembly. Anomalies #1, #2, #4, #5, #6, and #7 were electrical problems associated with the critical components that affect reliability. Although, all of these anomalies would have been detected by the electrical flight testing and, therefore, would not have decreased reliability. Even though Anomaly #5 would be detected by flight testing, this problem required extensive troubleshooting before being resolved. Prolonged troubleshooting at CCAFS may have delayed the testing and affected the launch schedule.

Anomaly #8 was not hardware related but was listed in Appendix C as a significant problem because of the schedule delay that occurred in resolving the paper anomaly. In this case, acceptance testing discovered a non-significant problem that would have caused a major delay in the flight testing at CCAFS.

Anomaly #3 involved a problem in an accelerometer, a

non-critical component of the IUS, that would not affect reliability. The problem was discovered during the post-test reduction of the Environmental Measurement Unit (EMU) data. Flight testing does not include data reduction from the analog tapes but only tests for aliveness in the accelerometers. Therefore, the testing at CCAFS would not have discovered the faulty accelerometer and EMU, however, the failures in these components would not have jeopardized the mission.

IUS-7. There were three hardware anomalies associated with factory testing of the IUS-7 vehicle. Anomaly #1 and Anomaly #3 concerned problems with non-critical components that do not affect reliability; yet, both problems would have been detected by the flight testing. Anomaly #2 involved a problem in the Power Distribution Unit (PDU) one of the critical reliability components. Once again, this problem would be detected by flight testing and would not affect reliability.

IUS-8. There were three hardware anomalies associated with factory testing of the IUS-8 vehicle. Anomaly #2 was a mechanical problem involving one cable that did not conform to specifications. This problem would have been detected during the vehicle assembly operations at CCAFS. Anomaly #1 and Anomaly #3 were failures in critical components of the vehicle. However, both anomalies would have been discovered during flight testing, and therefore, would not decrease reliability.

IUS-17. There were four hardware anomalies associated with factory testing of the IUS-17 vehicle. Anomaly #4 was a mechanical problem with a covering fabric that required the removal of the actuators. This problem would have been detected during the receiving inspection performed at CCAFS, and the actuator retest would have been accomplished during the normal flight testing. Anomalies #1, #2, and #3 concerned electrical problems in the Transponder and the TVCs. All of these problems would have been detected during the flight testing and would not affect the reliability of the vehicle.

IUS-18. There were three hardware anomalies associated with factory testing of the IUS-18 vehicle. Anomaly #3 was a mechanical problem that concerned a torn cable connector grommet. The connector was used as is since the anomaly did not affect the electrical or mechanical functions of the connector. Anomaly #1 involved a non-critical component of the vehicle that did not affect reliability. Anomaly #2 involved one of the computers which is a critical component. However, both of these problems would be detected by the flight testing.

IUS-19. There were four hardware anomalies associated with factory testing of the IUS-19 vehicle. Anomaly #1 and Anomaly #2 were mechanical problems discovered during leak tests that showed faulty connections. These problems would not have been detected by flight testing at CCAFS. However, the requirement to perform helium leak checks has been

deleted for all future vehicles. Additionally, this paper only suggests deleting the electrical portion of the acceptance testing and is not recommending the deletion of mechanical leak checks. Therefore, these anomalies would not affect the mission reliability.

Anomaly #4 was an electrical fault in both of the computers, a critical component of the vehicle. However, this failure would have been discovered by the flight testing. This anomaly has occurred before in the flight testing but will no longer be a problem because of modifications made in the components.

Anomaly #3 involved a short in an electrical circuit that was caused by a cut in the insulation covering the line terminals. This problem was discovered during the power compatibility test performed as part of the electrical acceptance testing. The problem would have been discovered at CCAFS when power was applied to the vehicle, but critical components may have been damaged when voltage was applied to the short circuit. The current flight testing does not include a power compatibility test, so it would not have detected the problem before power was applied.

Reliability Estimation

After analyzing the anomalies from acceptance testing, the next phase of the research involved determining the possible affect on reliability should acceptance testing be deleted. As discussed above, out of the total of 387

anomalies involved in this study, only two hardware failures (IUS-6 Anomaly #3, and IUS-19 Anomaly #3) would not have been detected during the flight testing at CCAFS. However, only one of these failures (IUS-19 Anomaly #3) involved a problem in a critical component that is used in determining the theoretical vehicle reliability. The other hardware failure (IUS-6 Anomaly #3) did not involve any critical components, and therefore, not detecting this failure in flight testing would not decrease reliability. Then, the total number of failures that might affect the mission reliability and that would not be detected by flight testing only equals one.

The system reliability measurement consists of an estimation of the system's mean time between failures using a ratio of the total accumulated operating time to the number of failures that occur during testing. Using Equation (3) from Chapter 3, the total accumulated operating time (T) equals 3960 hours for the 15 critical components used to calculate vehicle reliability.

$$T = 15\ components * 33\ \frac{hours}{component} = 3960\ hours$$

Then using Equation (2), the mean time between failures (m) equals 3960 hours when the total number of failures (r) equals 1 since only one anomaly would not be detected by flight testing.

$$m = \frac{T}{r} = \frac{3960}{1} = 3960 \; hours$$

As discussed in Chapter 3, reliability theory has determined that system reliability measurements are limited to chance failures and can be calculated using the exponential Equation (1). In this equation, the operating time for the system (t) will be 12 hours which is the average mission time for a typical IUS vehicle flown aboard the Space Transportation System (STS). Then, the estimated new reliability of the IUS resulting from the deletion of acceptance testing is

$$R_{New} = e^{-\frac{t}{m}} = e^{-\frac{12}{3960}} = 99.70\%$$

Therefore, by deleting the electrical portion of the factory acceptance testing, the reliability of the IUS vehicle will only decrease .03% from the theoretical reliability of 99.73% to an estimated reliability of 99.70%.

This calculated decrease in reliability is only significant to the extent that it reflects a "possible" change in mission reliability when test time is decreased. However, vehicle reliability might not be affected by any significant level from the current value of 99.73% since this percentage is only a theoretical value determined from the IUS component reliabilities and may possibly be higher than the actual reliability demonstrated during previous IUS missions. Consequently, eliminating the acceptance testing

might not change the actual reliability of the IUS but would only maintain it at its current level while the theoretical reliability would be decreased insignificantly.

Cost-Benefit Results

For the seven IUS vehicles involved in this study, the average cost of performing factory acceptance testing was \$1.75 million per vehicle. From this cost, \$750,000 was attributed to the electrical portion of the testing and \$1 million was attributed to acoustic testing. Thus, by deleting the electrical factory testing, the IUS program would benefit from a savings of \$750,000. However, there is a cost associated with the decreased reliability that was estimated earlier. (23)

The expected cost of a decrease in reliability is a function of the cost of the launch vehicle, the upper stage, and the satellite. This analysis assumed the use of the STS with an average cost of \$200 million per launch, the IUS with an average cost of \$60 million, and a non-specific satellite with an average cost of \$85 million. The expected cost of decreased reliability was calculated using the estimated new reliability and Equation (5) from Chapter 3. This cost then becomes

$$Cost = (.9973 - .9970) * (200 + 60 + 85)\ \$\ million = \$103,500$$

This value is the cost to the IUS program of the decreased reliability, or it can be thought of as the additional expense of improving reliability from 99.70% to 99.73%. Consequently, since the highest possible reliability is desired for any program, the calculated value of $103,500 becomes a cost to the IUS program for decreased reliability when testing is eliminated. Even though, by deleting the electrical portion of acceptance testing for each IUS vehicle, the IUS program would incur a net savings of $646,500 per vehicle. The results of the cost-benefit analysis are summarized in Table 2.

TABLE 2

COST-BENEFIT RESULTS

	CURRENT	SUGGESTED
Reliability	99.73%	99.70%
Acceptance Test Costs	$1.75M	$1.0M
Cost of Reliability	$0.0	$0.1035M
Total Costs	$1.75M	$1.1035M

Net Savings: $1.75M - $1.1035M = $646,500 per vehicle

Summary

This chapter presented the results of the data analysis performed on the seven IUS acceptance test logs and discussed those anomalies that might have impacted the reliability of the IUS vehicle. The research discovered two

anomalies that occurred during acceptance testing that would not have been detected by flight testing, but only one of these anomalies may have decreased reliability. This one failure was used as the basis for estimating the new reliability of 99.70%, a .03% decrease in reliability. This estimate was then used to calculate the cost of decreased reliability of $103,500. Finally, a cost-benefit analysis was performed that showed by deleting the electrical portion of factory acceptance testing, the IUS program could save $646,500 per vehicle.

The next chapter, Conclusions and Recommendations, provides the resolutions to the research questions proposed in Chapter 1 that were answered during the research effort and recommends further areas for study.

V. Conclusions and Recommendations

Introduction

This chapter provides a summary of the work performed to complete this research effort, suggestions for further research, and some concluding remarks. The research findings are discussed in the context of the problem statement and the conclusions reached follow the structure of the research questions presented in Chapter 1.

Conclusions

As part of the Air Force's attempt at Total Quality Management, Air Force Systems Command has requested that all operational space programs evaluate their current assembly, test, and launch operations for possible cost reductions. The research objective of this paper was to complete an analysis of the existing IUS processing to determine if any of the repetitive testing could be eliminated from the processing flow. The research also addressed the cost savings associated with the possible deletion of testing and the effect on overall vehicle reliability. The results of this research can be summarized in the answers to the following research questions.

Research Question #1. How many vehicles should be analyzed for anomalies?

Since the program's initial conception in 1978, thirteen IUS vehicles have successfully completed factory acceptance testing and launch operations. From 1978 until January 1986, there were minimal changes in the testing process and test operators. However, after the explosion of the space shuttle Challenger in January 1986, IUS vehicle processing was delayed until the shuttle was cleared for flight. Because of this delay, changes were implemented into the IUS program and new personnel were brought into the test program when operations were resumed. As a result, this research analyzed only those seven IUS vehicles that have completed factory acceptance testing and have successfully finished their missions since 1986.

Research Question #2. Which test phase is the better candidate for elimination?

The IUS normally undergoes acceptance testing approximately three to four years before its scheduled launch. During this delay, the vehicle is put into storage at the factory until it is prepared for shipment to CCAFS. Because of the prolonged time in storage, inert motors are used for acceptance testing because they will surpass their storage limitations. Additionally, some non-flight

components are used in acceptance testing because their calibrations will be invalidated during the time in storage.

After completion of acceptance testing and storage, the IUS is disassembled to remove the inert motors and non-flight components and because of the limitations imposed on transporting the vehicle from the factory to CCAFS. The IUS is then reassembled at CCAFS with live motors and pedigreed components to perform flight testing and launch operations. Furthermore, the current program requirements dictate that any electrical connections that are broken must be totally retested after reassembly to ensure continuity and functionality. Therefore, the storage limitations and retest requirements suggest that the acceptance test is the only logical test that may be eliminated.

<u>Research Question #3</u>. What design faults or workmanship defects will go undetected?

By analyzing the 387 anomalies that occurred during acceptance testing for the seven vehicles involved in this study and by comparing these failures to the flight testing, the research has suggested that only two hardware defects from the factory would not be detected by flight testing. One of these anomalies involved a short in an electrical circuit that was detected by a power compatibility test. A failure in this circuit might have shorted out a critical flight component that would affect the vehicle reliability.

The other hardware failure concerned a fault in an accelerometer which is not a critical component used to calculate vehicle reliability. The problem was discovered during the post-test reduction of the EMU data. Flight testing does not include data reduction from the analog tapes but only tests for aliveness in the accelerometers. However, not detecting this failure in flight testing would not decrease reliability.

Research Question #4. How much money can be saved?

For the seven IUS vehicles involved in this research, the average cost of performing the electrical portion of acceptance testing was $750,000. If all defects from acceptance testing would be detected by the flight testing, then by deleting this phase of testing for all future vehicles, the IUS program costs could be reduced by $750,000 per vehicle with no decrease in reliability. However, the research has indicated that two failures would not be detected by flight testing and that one failure might impact the reliability of the IUS. Therefore, the total savings of $750,000 per vehicle to the IUS program will be reduced by an amount equal to the decrease in reliability. This cost will be addressed in Research Question #6.

Research Question #5. What is the effect on vehicle reliability?

Under the current testing scenario, the IUS operates to a theoretical reliability of 99.73%. This reliability is obtained from the combination of reliabilities of the fifteen serial and parallel components listed in Table 1. The system reliability resulting from the deletion of electrical acceptance testing consists of an estimation of the system's mean time between failures using a ratio of the total accumulated operating time to the number of failures that occur during testing. The new system reliability can then be determined using the chance failure model and is calculated by an exponential equation that implements this estimated mean time between failures.

As shown in Chapter 4, the new vehicle reliability obtained during this research was estimated to be 99.70%. Therefore, by deleting the electrical portion of the factory acceptance testing, the reliability of the IUS vehicle will only decrease .03% from the theoretical reliability of 99.73% to an estimated reliability of 99.70%.

This calculated decrease in reliability is only significant to the extent that it reflects a "possible" change in mission reliability when test time is decreased. However, vehicle reliability might not be affected by any significant level from the current value of 99.73% since this percentage is only a theoretical value determined from

the IUS component reliabilities and may possibly be higher than the actual reliability demonstrated during previous IUS missions. Consequently, eliminating the acceptance testing might not change the actual reliability of the IUS but would only maintain it at its current level while the theoretical reliability would be decreased insignificantly.

Research Question #6. What is the relationship between cost savings and the possible change in reliability?

As discussed in Research Question #4, deleting the electrical portion of acceptance testing will reduce the IUS program costs by $750,000 per vehicle. However, there is a cost associated with the estimated decreased reliability of 99.70%. As shown in Chapter 3, the expected cost of a decrease in reliability is a function of the cost of the launch vehicle processing, the upper stage, and the satellite. This analysis assumed the use of the STS with an average cost of $200 million, the IUS with an average cost of $60 million, and a non-specific satellite with an average cost of $85 million. Then the expected cost of decreased reliability from the theoretical value of 99.73% resulting from the deletion of acceptance testing was calculated to be $103,500.

This value is the cost to the IUS program of the decreased reliability, or it can be thought of as the additional expense of improving reliability from 99.70% to

99.73%. Since the highest possible reliability is desired in any program, the calculated value of $103,500 becomes a cost to the IUS program for decreased reliability when testing is deleted. Even though, by eliminating the electrical portion of factory acceptance testing, the IUS program would incur a net savings of $646,500 per vehicle.

Conversely, as discussed above in Research Question #5, the elimination of acceptance testing might not decrease the vehicle reliability from its actual demonstrated value but would only maintain it at its current level. Then the savings to the IUS program would equal $750,000, the cost of performing the electrical acceptance testing.

Research Question #7. What conclusions and recommendations can be drawn from this research?

First, the research has suggested that considerable cost savings in the IUS program could be achieved by deleting the electrical phase of factory acceptance testing even with the minor decrease in vehicle reliability. However, vehicle reliability could be maintained at its current level by implementing additional testing at CCAFS for detection of those failures that are currently not tested for, because of the acceptance testing. As an example, a short in an electrical circuit of IUS-19 was discovered by performing a power compatibility test as part of the acceptance test. If acceptance testing had been

deleted and this defect not been detected, considerable damage to the vehicle may have occurred when power was applied for flight testing. By performing a power compatibility test at CCAFS before initial power application, this problem would have been detected. Furthermore, this particular test has been performed on an earlier vehicle at CCAFS so the necessary resources exist for implementation, and the only impact to flight testing would be additional time in the schedule.

Secondly, government acceptance of the IUS from the contractor could be delayed until completion of flight testing. Currently, the government officially accepts responsibility for the vehicle (DoD Form 250) after completion of acceptance testing when all systems have been successfully demonstrated. Should acceptance testing be eliminated, successful operation of systems will not be demonstrated until after completion of flight testing. Therefore, to maintain the level of risk to the government, vehicle acceptance could be delayed until after the completion of the initial phases of flight testing.

Finally, the time saved by deleting acceptance testing should be built into the flight testing. One of the benefits of performing acceptance testing is to screen the test procedures and test software for errors. Any errors that can be corrected during this phase of testing will eliminate problems during flight testing when the same procedures and software are used. Additionally, all

problems that were otherwise corrected at the factory now must be corrected at CCAFS. The removal and retest of flight components can be a time consuming process, so additional time must be available in the launch schedule.

Further Research

Although much was accomplished in this study, there are some areas of study that could be researched in greater detail. These studies could provide additional information for the IUS program to determine the consequences of eliminating the factory acceptance testing.

First, further research could expand upon the work completed in this thesis. Performing the same analysis on all IUS vehicle since the program's inception, as well as those vehicles that have completed acceptance testing but have not yet undergone launch operations could supplement the validation of this study. To refine the net costs that could be achieved by the deletion of acceptance testing, the costs of implementing additional testing, the costs of modifying the existing contract to reflect the changes, and the impact of moving personnel from the factory to CCAFS could be researched.

Secondly, the literature review found limited information on the importance of acceptance testing in major "one-use" systems. A survey of test engineers from government laboratories and civilian contractors could investigate the negative sentiments toward acceptance

testing that was proposed in an earlier survey by Smith and Matteson (19:72). The results of this survey could then be used to question the validity of acceptance testing for the IUS program as well as many other major programs. The elimination of unnecessary operations and repetitive processing would reduce total program costs and would benefit the Air Force's goal of Total Quality Management.

Recommendations

Based on this limited analysis and the previous discussion, this research cannot unconditionally support either a recommendation to continue or to delete the current IUS factory acceptance testing. Further research is recommended to construct a more objective, formative evaluation of the current testing operations to assist the IUS Program Office in their decision.

Appendix A: Acronyms

AFSC	Air Force Systems Command
AFSPACECOM	Air Force Space Command
AIAA	American Institute of Astronautics and Aeronautics
ASC	The Aerospace Corporation
AU	Air University
A/V	Avionics
BAC	Boeing Aerospace Company
CCAFS	Cape Canaveral Air Force Station
COS	Checkout Station
DoD	Department of Defense
DODD	Department of Defense Directive
DODI	Department of Defense Instruction
DT&E	Developmental Test and Evaluation
ELS	Eastern Launch Site
EMU	Environmental Measurement Unit
FOT&E	Follow-on Operational Test and Evaluation
GSE	Ground Support Equipment
IMU	Inertial Measurement Unit
IUS	Inertial Upper Stage
KSC	Kennedy Space Center
NASA	National Aeronautic and Space Administration
NASP	National Aerospace Plane
OT&E	Operational Test and Evaluation
PDU	Power Distribution Unit
PSU	Pyro Switching Unit
PTU	Power Transfer Unit
RCS	Reaction Control System
RIMU	Redundant Inertial Measurement Unit
S/C	Spacecraft
SCU	Signal Conditioning Unit
SDI	Strategic Defense Initiative
SIU	Signal Interface Unit
S/N	Serial Number
SPG	Single Point Ground

T&E	Test and Evaluation
TQM	Total Quality Management
TVC	Thrust Vector Control
USAF	United States Air Force
VDC	Volts Direct Current

Appendix B: ASC Engineering Review Team

Name	Job Title
James H. Beardall	IUS Systems Manager
Jerry J. Brokaw	IUS Electrical Systems Engineer
Steven P. Crane	IUS Electrical Systems Engineer
Thomas S. Hill	IUS Systems Requirements
Edward R. Layman	IUS Electrical Systems Engineer
A.A. (Mundy) Macias	Quality Control/Configuration Management
Jacob Vogler	Guidance, Navigation, and Control Engineer

Appendix C: Acceptance Test Problems and Resolutions

This appendix summarizes the results of the Kent factory testing as presented to the USAF for acceptance of the seven IUS vehicles under study. Each acceptance test package lists the significant problems that were encountered during the electrical testing; however, in some instances, mechanical problems encountered during vehicle build-up are also presented. Table 3 contains a categorical listing of the total number of anomalies that were disclosed to the government before the formal acceptance of each vehicle. The remainder of this appendix summarizes the electrical hardware anomalies and any other anomalies associated with each IUS that are significant to this study.

TABLE 3

RESULTS OF FACTORY ACCEPTANCE TESTING

Vehicle	Paper	Operator	Test Equipment	Hardware
IUS-5	44	19	25	5
IUS-6	66	3	4	41 *
IUS-7	49	1	3	3
IUS-8	28	8	5	3
IUS-17	8	2	1	4
IUS-18	30	14	10	3
IUS-19	0	0	2	5

* The IUS-6 Acceptance Test Package contained seven electrical and 34 mechanical anomalies associated with testing and vehicle build-up.

IUS-5 Significant Anomalies (13)

1. B843949 - Telemetry parameter U76X0034E, Thrust Vector Control (TVC) A Avionics (A/V) Power ON, indicated OFF (0) after commanded ON (1). Discovered wires were not connected at connector P018. Connector P018 was removed and replaced with all wires reterminated.

2. B821299 - Locking pins were not visible on the A-side Power Distribution Unit (PDU) J6 connector. Tightened connector and verified locking pins were visible.

3. Z825712 - Accelerometer dislodged during post-acoustic inspection. Data reduction indicated the accelerometer to be suspect. The accelerometer was removed, replaced, and rebonded successfully.

4. Z934493 - Actuator bellows showed signs of deterioration during the de-stack operations. Actuators were rejected and replaced.

5. B831702 - Telemetry parameter U71M3029D, Redundant Inertial Measurement Unit (RIMU) CH 3, went out-of-alarm upon application of power. This indicated failed power supply on CH 3. Authorization was obtained to disable CH 3 power for completion of planned factory testing. The RIMU was removed and replaced prior to the ELS testing.

<u>IUS-6 Significant Anomalies</u> (14)

1. B504861 - Breakout pins 1A and 2B indicated 50 mV when test procedure called for 29 +/- 3 VDC. The PDU was removed and replaced and retested successfully.

2. B502260 - Power scenario halted because the computer A telemetry was not received at the checkout station within the allotted time. Computer A was removed and replaced. The anomaly was not recreated with the new computer.

3. B502268 - Reduction of the Environmental Measurement Unit (EMU) data from the analog tapes indicated that there was no data on channel 2 vibration accelerometer. The vibration accelerometer block and the EMU were removed, replaced, and retested successfully.

4. B502235 - RIMU S/N 009 indicated a problem during electrical testing. The RIMU was replaced with S/N 010 and retested satisfactorily per the test instructions.

5. B815303 - Test point 5 to Single Point Ground (SPG) measures 2500 milliohms, but should be less than or equal to 500 milliohms. The PDU was removed and replaced. During the retest operations, another resistance measurement failed. After extensive troubleshooting, it was discovered that three relays in the PDU were in the wrong position. The relays were repositioned and retest continued.

6. B814703 - Telemetry parameter U76X0037E read '0' but should have been '1'. The wire to pin #36 was found to be broken at the back of the contact. The wire and contact were repaired and retested successfully.

7. B815313 - Telemetry parameter U71M3029D read '001203 but should have been '000203'. The anomaly was isolated to the RIMU S/N 0017. The RIMU was removed per the schedule and returned to the vendor for modification.

8. B504851 - When scenario 'TON' is executed, measurement U90X4229E goes out of alarm limits. Test was rerun satisfactorily utilizing a software patch. This anomaly is not a hardware problem, but is documented to demonstrate the schedule delay that may occur in developing a software patch.

<u>IUS-7 Significant Anomalies</u> (15)

1. B560674 - Telemetry response for RCS heaters B side failed intermittently. Pin 25 of connector P035 was broken. The failed pin was replaced and retested successfully.

2. B631377 - PDU S/N 017 failed the Single Point Ground check. Removed and replaced PDU with S/N 023 and retested. The failed PDU was found to have a clamp screw interference problem.

3. B631394 - EMU vibration accelerometer failed to respond to dynamic stimulus. Accelerometer was replaced and retested successfully. A faulty splice was found to be the cause of the anomaly.

<u>IUS-8 Significant Anomalies</u> (16)

1. B655496 - Scenario 'TF2' halted with multiple out-of-limit warnings and the message: "Command at Controller Failure." Corrected the connection to the stage 2 pitch potentiometer. Inspection and X-rays showed no damage occurred.

2. B655446 - Cable W003 exceeded the allowable bend radius and protruded above the plane of the spacecraft interface. The cable was inspected and repositioned to conform with the correct specifications.

3. Z833010 - A/V Bus B Current went out of lower alarm limits. The PDU-B current sensor was discovered to be faulty. Removed and replaced the discrepant PDU and retested successfully.

IUS-17 Significant Anomalies (17)

1. B928418 - Receiver Loop Stress telemetry measurement was not within allowable limits. The Cubic Transponder was removed and replaced with a TRW transponder and successfully retested.

2. B929358 - TVC Stage 1B fault caused reconfiguration and test failure. The TVC controller, actuator, and potentiometer were replaced and retested successfully.

3. B928403 - A failure in the TVC halted the test scenario and caused vehicle reconfiguration. The problem was isolated to the Stage 2 potentiometer to actuator cable W109. The cable was replaced and retested.

4. B929381 - The scrim cloth was separated from the bellows on two actuators. The actuators were removed and replaced and successfully retested during ELS flight testing.

IUS-18 Significant Anomalies (18)

1. B821224 - Spacecraft (S/C) Ring Temperature telemetry parameter went out of limits upon initial power application. Problem was due to a bad temperature sensor. The faulty sensor was removed, replaced, and successfully retested.

2. B821227 - During the TVC Phasing test, many telemetry parameters went out of limits and computer B (CU B) took control. The problem was traced to computer A having double bit memory errors causing CU A to go bad. The faulty computer was removed, replaced, and retested. This specific computer failure has been corrected by modifications in all computer units.

3. B821291 - The connector on cable W144 showed a torn grommet. The connector was used as is since the anomaly did not affect the electrical or mechanical functions of the connector.

IUS-19 Significant Anomalies (19)

1. B843966 - Two connections of the Radioisotope Thermal Generator (RTG) coolant lines did not pass initial leak test prior to the acoustic runs. Both connections were disassembled, cleaned, and reassembled. One connector required the installation of a washer. Retest was successful.

2. B843969 - Four of the six instrument purge line connections did not pass the helium leak check prior to the acoustic runs. The fittings were replaced and retested using a nitrogen leak check. The helium leak check requirement has been deleted.

3. B882508 - Failed power compatibility test at PDU B due to a short in the RCS line heater circuit. Troubleshooting revealed a nick in the insulation covering on the RCS line heater terminals. The heater was repaired and retested successfully. No voltage was applied to the circuit so the short did not cause any vehicle damage.

4. B832137 - During the TVC Phasing test, both computers failed with single or double bit memory errors. Both computers were removed and replaced with modified computers and retested successfully.

Bibliography

1. Bazovsky, Igor. *Reliability Theory and Practice.* Englewood Cliffs NJ: Prentice-Hall, Inc., 1961.

2. Bowman, Maj Richard L., II. "Space - The Logistics Challenge," *Air Force Journal of Logistics, 2*: 12-15 (Spring 1986).

3. Chasen, S. H. "Optimum Developmental Launch Programs," *Proceedings of the IAS Aerospace Systems Reliability Symposium.* 98-102. New York: Institute of the Aerospace Sciences, 1962.

4. Crane, Steven P., Inertial Upper Stage Electrical Systems Engineer. Telephone Interviews. The Aerospace Corporation, Cape Canaveral AFS FL, 27 March through 10 June 1991.

5. Department of the Air Force. "Inertial Upper Stage," *United States Air Force Fact Sheet.* 88-105. Los Angeles: HQ Space Division (AFSC), 1988.

6. Department of the Air Force. *Introduction to System Acquisition Management.* Text for SMGT 643. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, Winter 1991.

7. Department of Defense. *Defense Acquisition Management Policies and Procedures.* DOD Instruction 5000.2. Washington: Government Printing Office, 15 September 1990.

8. Funk, Kennerly W. and Richard Loraine. *Test and Evaluation for an Air-Launched Guided Missile Program.* MS thesis, Naval Postgraduate School, Monterey CA, December 1977 (AD-A048675).

9. Hord, Michael R. *Handbook of Space Technology: Status and Projections.* Boca Raton FL: CRC Press, Inc., 1985.

10. Houston, Edward S. and Mark W. Phillips. "Air Force Space Requirements: Can Industry Meet the Challenge for Space Systems?," *Proceedings of the 24th Space Congress.* 11-75 - 11-85. 1987.

11. Hudson, Gary C. and others. "A Modular Low Cost Launch Vehicle System: The Percheron Project," *Proceedings of the Fifth Princeton/AIAA Conference.* 311-318. New York: AIAA Press, 1981.

12. Inertial Upper Stage Group. *Acceptance, Checkout, Retest, and Backout Criteria*. Technical Operating Report D290-10301. Requirements Department, Boeing Aerospace Company, Kent WA, August 1988.

13. Inertial Upper Stage Group. *IUS-5 Kent Acceptance Review Test Results and Requirements*. Report to DOD Acceptance Team. Configuration Management Department, Boeing Aerospace Company, Kent WA, 8 February 1989.

14. Inertial Upper Stage Group. *IUS-6 Vehicle Log Book*. Report to DOD Acceptance Team. Configuration Management Department, Boeing Aerospace Company, Kent WA, 28 October 1988.

15. Inertial Upper Stage Group. *IUS-7 Acceptance Test Anomalies & Corrective Action*. Report to DOD Acceptance Team. Configuration Management Department, Boeing Aerospace Company, Kent WA, 14 October 1983.

16. Inertial Upper Stage Group. *IUS-8 Kent Acceptance Test Problems and Resolutions*. Report to DOD Acceptance Team. Configuration Management Department, Boeing Aerospace Company, Kent WA, 8 January 1988.

17. Inertial Upper Stage Group. *IUS-17 Kent Acceptance Test Problems and Resolutions*. Report to DOD Acceptance Team. Configuration Management Department, Boeing Aerospace Company, Kent WA, 5 December 1989.

18. Inertial Upper Stage Group. *IUS-18 Kent Acceptance Test Problems and Resolutions*. Report to DOD Acceptance Team. Configuration Management Department, Boeing Aerospace Company, Kent WA, 18 October 1988.

19. Inertial Upper Stage Group. *IUS-19 Significant Kent Acceptance Test Problems and Resolutions*. Report to DOD Acceptance Team. Configuration Management Department, Boeing Aerospace Company, Kent WA, 12 May 1989.

20. Lawrence, H. R. and J. M. Vogel. "Some Thoughts on Reliability Estimation," *Proceedings of the IAS Aerospace Systems Reliability Symposium*. 61-66. New York: Institute of the Aerospace Sciences, 1962.

21. Lloyd, David K. and Myron Lipow. *Reliability: Management, Methods, and Mathematics*. Englewood Cliffs NJ: Prentice-Hall, Inc., 1962.

22. Locurto, Charles A. and others. "Reliability Test Optimization," *Proceedings of the IAS Aerospace Systems Reliability Symposium*. 87-97. New York: Institute of the Aerospace Sciences, 1962.

23. Selter, Ronald M., Member of the IUS Technical Staff. Telephone Interviews. The Aerospace Corporation, Los Angeles CA, 30 April through 11 June 91.

24. Smith, Anthony M. and Thomas D. Matteson. "Needed: Rational Testing of Aerospace Vehicles," *Journal of Astronautics and Aeronautics, 11 (8)*: 69-72 (August 1973).

25. Summers, Capt Paul A. *Space Logistics: An Exploratory Study of the Comprehensiveness of United States Space Logistics Policy*. MS thesis, AFIT/GLM/LSM/89S-63. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1989 (AD-A138355).

26. Sutton, Lt Col E. B. and others. "Air Force Logistics Command Space Logistics Strategic Issues and Options," Report to AFLC Senior Leadership. HQ AFLC, Wright-Patterson AFB OH, 17 November 1988.

27. Woodcock, Gordon R. "Rethinking Our Space Future," *Proceedings of the Fifth Princeton/AIAA Conference*. 295-299. New York: AIAA Press, 1981.

Vita

Captain Michael H. Horn was born on 23 August 1963 in Manchester, Tennessee. He graduated from Tullahoma High School in Tullahoma, Tennessee in 1981 and attended the University of Notre Dame, graduating with a Bachelor of Science in Electrical Engineering in May 1985. He was commissioned at that time through Air Force ROTC. In October 1985 he served his first tour at Cape Canaveral AFS, Florida as the Inertial Upper Stage Electrical Interface Engineer for the 6555th Aerospace Test Group where he developed and directed electrical testing between the IUS, the space shuttle, and the Titan IV launch vehicle. In October 1988, he was chosen as the lead vehicle engineer for IUS-18 and the Magellan spacecraft and served as the director of testing until its launch in May 1989. He was then chosen to serve as the lead electrical engineer for IUS-6 until entering the School of Systems and Logistics, Air Force Institute of Technology, in May 1990.

Permanent Address: 110 Fairview School Road
Normandy, Tennessee 37360

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1991

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE
A COST-BENEFIT ANALYSIS ON THE DELETION OF THE INERTIAL UPPER STAGE FACTORY ACCEPTANCE TESTING VERSUS A DECREASE IN MISSION RELIABILITY

5. FUNDING NUMBERS

6. AUTHOR(S)
Michael H. Horn, Captain, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology, WPAFB OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GSM/ENS/91S-13

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This study investigated the benefits attributable to deleting the factory acceptance testing for the Inertial Upper Stage (IUS) space booster and the possible impacts on mission reliability. A review of the literature revealed limited research on the advantages or disadvantages of performing acceptance testing on commercial programs. However, a review of DoD policy recognized the advantages of cost and time savings when developmental and operational tests are combined. An analysis was performed on the anomalies that occurred during the acceptance testing for the vehicles involved in this study to determine whether all hardware defects would be detected by a later phase of testing. The research suggested that only two chance failures would be undetected by flight testing resulting in a decrease in reliability of .03% and a savings of $646,500 per IUS vehicle if acceptance testing was eliminated. The study concluded that current reliability could be maintained by additional flight testing but further research was necessary before a modification to the program could be implemented.

14. SUBJECT TERMS
Reliability, Test and Evaluation, Space Technology, Acceptance Tests, Cost Analysis, Anomalies

15. NUMBER OF PAGES
80

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std 239-18
298-102

AFIT Control Number AFIT/GSM/ENS/91S-13

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